OECD GUIDELINES FOR THE TESTING OF CHEMICALS

Vapour Pressure

INTRODUCTION

1.   This guideline is a revised version of the original Guideline 104 which was initially adopted in 1981 and subsequently updated in 1995. One additional method, Effusion method: isothermal thermogravimetry, is included in this version. The original guideline was developed based on the EC method "Vapour Pressure" published in 1992 (1) and in 2001 an additional method designed for chemicals with very low pressures (down to 10^{-10} Pa) was proposed by BASF. In the light of needs for methods especially in relation to obtain vapour pressure for substances with low vapour pressure, other methods of this guideline are re-evaluated with respect to other applicability ranges.

INITIAL CONSIDERATION

2.   At the thermodynamic equilibrium, the vapour pressure of a pure substance is a function of temperature only. The fundamental principles are described elsewhere (2) (3).

3.   No single measurement procedure is applicable to the entire range of vapour pressures from less than 10^{-10} to 10^5 Pa. Eight methods for measuring vapour pressure are included in this guideline which can be applied in different vapour pressure ranges. The various methods are compared as to application and measuring range in Table 1. The methods can only be applied for compounds that do not decompose under the condition of the test. In cases where the experimental methods cannot be applied due to technical reasons, vapour pressure can also be estimated and a recommended estimation method is set out in the Annex.

DEFINITIONS AND UNITS

4.   The vapour pressure of a substance is defined as the saturation pressure above a solid or liquid substance.

5.   The SI unit of pressure, which is the pascal (Pa), should be used. Other units which have been employed historically are given hereafter, together with their conversion factors:

1 Torr	= 1 mm Hg	= 1.333×10^2 Pa
1 atmosphere	= 1.013×10^5 Pa	
1 bar	= 10^5 Pa	

The SI unit of temperature is the kelvin (K). The conversion of degrees Celsius to kelvin is according to the formula:

$$T = t + 273.15$$

where, T is the kelvin or thermodynamic temperature and t is the Celsius temperature.

Table 1

Measuring method	Substances		Estimated repeatability	Estimated reproducibility	Recommended range
	Solid	Liquid			
Dynamic method	Low melting	Yes	up to 25% 1 to 5%	up to 25% 1 to 5%	10^3 Pa to $2x10^3$ Pa $2x10^3$ Pa to 10^5 Pa
Static method	Yes	Yes	5 to 10%	5 to 10%	10 Pa to 10^5 Pa 10^{-2} Pa to 10^5 Pa [1]
Isoteniscope method	Yes	Yes	5 to 10%	5 to 10%	10^2 Pa to 10^5 Pa
Effusion method: vapour pressure balance	Yes	Yes	5 to 20%	up to 50%	10^{-3} to 1 Pa
Effusion method: Knudsen cell	Yes	Yes	10 to 30%	--	10^{-10} to 1 P
Effusion method: isothermal thermogravimetry	Yes	Yes	5 to 30%	up to 50%	10^{-10} to 1 Pa
Gas saturation method	Yes	Yes	10 to 30%	up to 50%	10^{-10} to 10^3 Pa
Spinning rotor method	Yes	Yes	10 to 20%	--	10^{-4} to 0.5 Pa

REFERENCE SUBSTANCES

6.   Reference substances do not need to be employed.   They serve primarily to check the performance of a method from time to time as well as to allow comparison between results of different methods.

PRINCIPLE OF THE TEST

7.   In general, the vapour pressure is determined at various temperatures. In a limited temperature range, the logarithm of the vapour pressure of a pure substance is a linear function of the inverse of the thermodynamic temperature according to the simplified Clapeyron-Clausius equation:

$$\log p = \frac{\Delta Hv}{2.3RT} + constant$$

where:

p =   the vapour pressure in pascals;
ΔHv =   the heat of vaporisation in J mol^{-1};
R =   the universal gas constant, 8.314 J mol^{-1} K^{-1};
T =   the temperature in K.

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[1] When using a capacitance manometer

DESCRIPTION OF THE METHODS

**Dynamic method (Cottrell's method)**

Principle

8.   The vapour pressure is determined by measuring the boiling temperature of the substance at various specified pressures between roughly 10^3 and 10^5 Pa. This method is also recommended for the determination of the boiling temperature. It is useful for that purpose up to 600 K. The boiling temperatures of liquids are approximately 0.1 °C higher at a depth of 3 to 4 cm than at the surface because of the hydrostatic pressure of the column of liquid. In Cottrell's method (4) the thermometer is placed in the vapour above the surface of the liquid and the boiling liquid is made to pump itself continuously over the bulb of the thermometer. A thin layer of liquid which is in equilibrium with vapour at atmospheric pressure covers the bulb. The thermometer thus reads the true boiling point, without errors due to superheating or hydrostatic pressure. The pump originally employed by Cottrell is shown in figure 1. The tube A contains the boiling liquid. A platinum wire B sealed into the bottom facilitates uniform boiling. The side tube C leads to a condenser, and the sheath D prevents the cold condensate from reaching the thermometer E. When the liquid in A is boiling, bubbles and liquid trapped by the funnel are poured via the two arms of the pump F over the bulb of the thermometer.

Figure 1   Figure 2
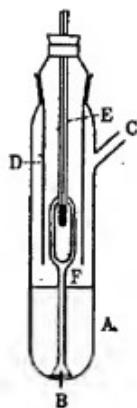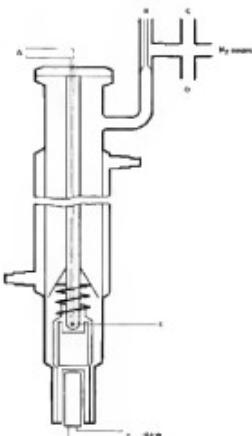
Cottrell pump (4)

A: Thermocouple
B: Vacuum buffer volume
C: Pressure gauge
D: Vacuum
E: Measuring point
F: Heating element c.a. 150 W

Apparatus

9.   A very accurate apparatus, employing the Cottrell principle, is shown in figure 2. It consists of a tube with a boiling section in the lower part, a cooler in the middle part, and an outlet and flange in the upper part. The Cottrell pump is placed in the boiling section which is heated by means of an electrical cartridge. The temperature is measured by a jacketed thermocouple or resistance thermometer inserted through the flange at the top. The outlet is connected to the pressure regulation system. The latter consists of a vacuum pump, a buffer volume, a manostat for admitting nitrogen for pressure regulation and manometer.

Procedure

10.   The substance is placed in the boiling section. Problems may be encountered with non-powder solids but these can sometimes be solved by heating the cooling jacket. The apparatus is sealed at the flange and the substance degassed. Frothing substances cannot be measured using this method.

11.   The lowest desired pressure is then set and the heating is switched on. At the same time, the temperature sensor is connected to a recorder.

12.   Equilibrium is reached when a constant boiling temperature is recorded at constant pressure. Particular care must be taken to avoid bumping during boiling. In addition, complete condensation must occur on the cooler. When determining the vapour pressure of low melting solids, care should be taken to avoid the condenser blocking.

13.   After recording this equilibrium point, a higher pressure is set. The process is continued in this manner until 10^5 Pa has been reached (approximately 5 to 10 measuring points in all). As a check, equilibrium points must be repeated at decreasing pressures.

<u>Static method</u>

Principle

14.   In the static method (5), the vapour pressure at thermodynamic equilibrium is determined at a specified temperature. This method is suitable for substances and multicomponent liquids and solids in the range from 10 to 10^5 Pa and, provided care is taken, also in the range 1 to 10 Pa.

Apparatus

15.   The equipment consists of a constant-temperature bath (precision of $\pm$ 0.2 K), a container for the sample connected to a vacuum line, a manometer and a system to regulate the pressure. The sample chamber (figure 3a) is connected to the vacuum line via a valve and a differential manometer (U-tube containing a suitable manometer fluid) which serves as zero indicator. Mercury, silicones and phthalates are suitable for use in the differential manometer, depending on the pressure range and the chemical behaviour of the test substance. However, based on environmental concerns, the use of mercury should be avoided, if possible. The test substance must not dissolve noticeably in, or react with, the U-tube fluid. A pressure gauge can be used instead of a U-tube (figure 3b). For the manometer, mercury can be used in the range from normal pressure down to 10^2 Pa, while silicone fluids and phthalates are suitable for use below 10^2 Pa down to 10 Pa. There are other pressure gauges which can be used below 10^2 Pa and heatable membrane capacity manometers can even be used at below 10^{-1} Pa. The temperature is measured on the outside wall of the vessel containing the sample or in the vessel itself.

Procedure

16.   Using the apparatus as described in figure 3a, fill the U-tube with the chosen liquid, which must be degassed at an elevated temperature before readings are taken. The test substance is placed in the apparatus and degassed at reduced temperature. In the case of a multiple-component sample, the temperature should be low enough to ensure that the composition of the material is not altered. Equilibrium can be established more quickly by stirring. The sample can be cooled with liquid nitrogen or dry ice, but care should be taken to avoid condensation of air or pump-fluid. With the valve over the sample vessel open, suction is applied for several minutes to remove the air. If necessary, the degassing operation is repeated several times.

Figure 3a   **Figure 3b**

1: Test substance
2: Vapour phase
3: High vacuum valve
4: Pressure gauge
5: Pressure indicator
6: U tube (auxiliary manometer)
7: Manometer
8: Temperature measuring device

1: Test substance
2: Vapour phase
3: High vacuum valve
4: U tube (auxiliary manometer)
5: Manometer
6: Pressure indicator
7: Temperature bath
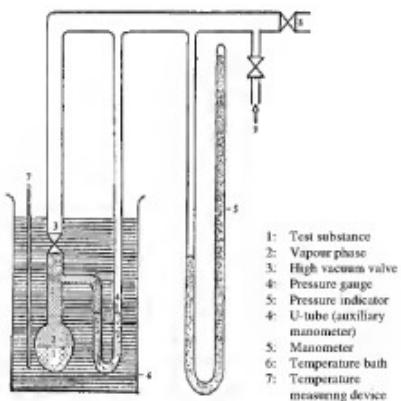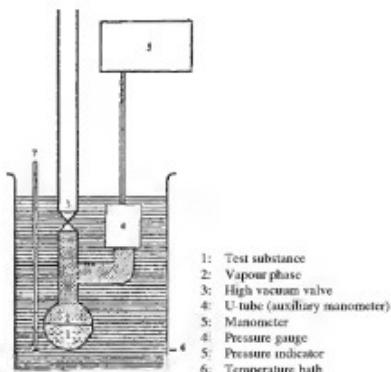
17.   When the sample is heated with the valve closed, the vapour pressure increases. This alters the equilibrium of the fluid in the U-tube. To compensate for this, nitrogen or air is admitted to the apparatus until the differential pressure indicator is at zero again. The pressure required for this can be read off the manometer or an instrument of higher precision. This pressure corresponds to the vapour pressure of the substance at the temperature of the measurement. Using the apparatus described in figure 3b, the vapour pressure is read off directly.

18.   The vapour pressure is determined at suitably small temperature intervals (approximately 5 to 10 measuring points in all) up to the desired temperature maximum.

19.   Low-temperature readings must be repeated as a check. If the values obtained from the repeated readings do not coincide with the curve obtained for increasing temperature, this may be due to one of the following situations:

   i.   the sample still contains air (e.g. in the case of highly viscous materials) or low-boiling substances which is or are released during heating;

ii.   the substance undergoes a chemical reaction in the temperature range investigated (e.g. decomposition, polymerization).

Isoteniscope Method

Principle

20.   The isoteniscope (6) is based on the principle of the static method. The method involves placing a sample in a bulb maintained at constant temperature and connected to a manometer and a vacuum pump. Impurities more volatile than the substance are removed by degassing at reduced pressure. The vapour pressure of the sample at selected temperatures is balanced by a known pressure of inert gas. The isoteniscope was developed to measure the vapour pressure of certain liquid hydrocarbons but it is appropriate for the investigation of solids as well. The method is usually not suitable for multicomponent systems. Results are subject to only slight errors for samples containing non-volatile impurities. The recommended range is 10^2 to 10^5 Pa.

Apparatus

21.   An example of a measuring device is shown in figure 4. A complete description can be found in ASTM D 2879-86 (6).

Procedure

22.   In the case of liquids, the substance itself serves as the fluid in the differential manometer. A quantity of the liquid, sufficient to fill the bulb and the short leg of the manometer, is put in the isoteniscope. The isoteniscope is attached to a vacuum system and evacuated, then filled by nitrogen. The evacuation and purge of the system is repeated twice to remove residual oxygen. The filled isoteniscope is placed in a horizontal position so that the sample spreads out into a thin layer in the sample bulb and manometer. The pressure of the system is reduced to 133 Pa and the sample gently warmed until it just boils (removal of dissolved gases). The isoteniscope is then placed so that the sample returns to the bulb and fills the short leg of the manometer. The pressure is maintained at 133 Pa. The drawn-out tip of the sample bulb is heated with a small flame until sample vapour released expands sufficiently to displace part of the sample from the upper part of the bulb and manometer arm into the manometer, creating a vapour-filled, nitrogen-free space. The isoteniscope is then placed in a constant temperature bath, and the pressure of nitrogen is adjusted until it equals that of the sample. At the equilibrium, the pressure of nitrogen equals the vapour pressure of the substance.

Figure 4
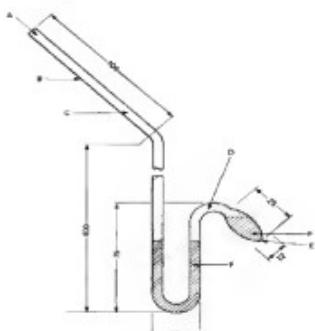
A: Pressure control
B: 8 mm OD Tube
C: Dry nitrogen in pressure system
D: Sample vapour
E: Small tip
F: Liquid sample

(Dimensions in mm)

23.   In the case of solids and depending on the pressure and temperature ranges, manometer liquids such as silicon fluids or phthalates are used. The degassed manometer liquid is put in a bulge provided on the long arm of the isoteniscope. Then the solid to be investigated is placed in the sample bulb and is degassed at elevated temperature. After that the isoteniscope is inclined so that the manometer liquid can flow into the U-tube.

Effusion method: vapour pressure balance (7)

Principle

24.   A sample of the test substance is heated in a small furnace, placed in an evacuated bell jar. The furnace is covered by a lid which carries small holes of known diameters. The vapour of the substance, escaping through one of the holes, is directed onto a balance pan of a highly sensitive balance which is also enclosed in the evacuated bell jar. In some designs, the balance pan is surrounded by a refrigeration box, providing heat dissipation to the outside by thermal conduction, and is cooled by radiation so that the escaping vapour condenses on it. The momentum of the vapour jet acts as a force on the balance. The vapour pressure can be derived in two ways: directly from the force on the balance pan and also from the evaporation rate using the Hertz-Knudsen equation (2):

$$p = G \sqrt{\frac{2\pi \, RT \times 10^3}{M}}$$

where:

G = evaporation rate (kg s^{-1} m^{-2});
M = molar mass (g mol^{-1});
T = temperature (K);
R = universal gas constant (J mol^{-1} K^{-1});
p = vapour pressure (Pa).

The recommended range is 10^{-3} to 1 Pa.

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Apparatus

25. The general principle of the apparatus is illustrated in figure 5.

Figure 5
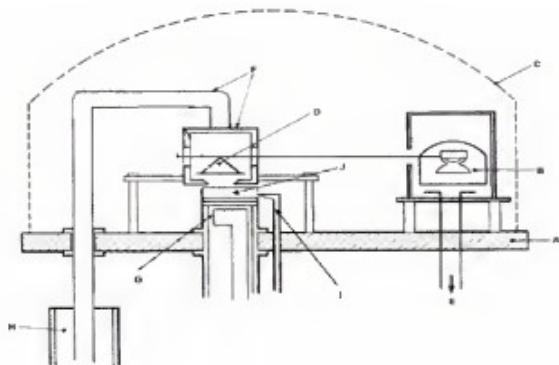
A: Base plate
B: Moving coil instrument
C: Bell jar
D: Balance with scale pan
E: Vacuum measuring device

F: Refrigeration box and cooling bar
G: Evaporator furnace
H: Dewar flask with liquid nitrogen
I: Measurement of temperature of sample
J: Test Substance

Effusion method: Knudsen cell

Principle

26. The method is based on the estimation of the mass of test substance flowing out per unit of time of a Knudsen cell (8) in the form of vapour, through a micro-orifice under ultra-vacuum conditions. The mass of effused vapour can be obtained either by determining the loss of mass of the cell or by condensing the vapour at low temperature and determining the amount of volatilized substance using chromatography. The vapour pressure is calculated by applying the Hertz-Knudsen relation (see paragraph 24) with correction factors that depend on parameters of the apparatus (9). The recommended range is 10^{-10} to 1 Pa (10)(11)(12)(13)(14).

Apparatus

27. The general principle of the apparatus is illustrated in figure 6.

Figure 6
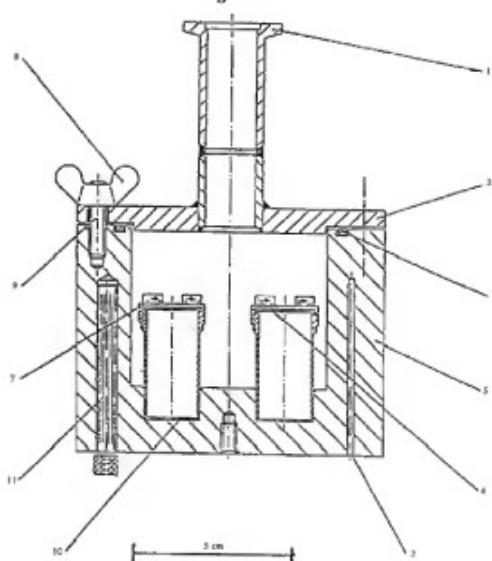
1: Connection to vacuum
2: Wells from platinum resistance thermometer or temperature measurement and control
3: Lid for vacuum tank
4: O-ring
5: Aluminum vacuum tank
6: Device for installing and removing the effusion cells
7: Threaded lid
8: Butterfly nuts
9: Bolts
10: Stainless steel effusion cells
11: Heater cartridge

Effusion method: isothermal thermogravimetry

Principle

28.   The method is based on the determination of accelerated evaporation rates for the test substance at elevated temperatures and ambient pressure using thermogravimetry (10)(15)(16)(17)(18)(19)(20). The evaporation rates v_T result from exposing the selected compound to a slowly flowing inert gas atmosphere, and monitoring the weight loss at defined isothermal temperatures T in Kelvin over appropriate periods of time. The vapour pressures p_T are calculated from the v_T values by using the linear relationship between the logarithm of the vapour pressure and the logarithm of the evaporation rate. If necessary, an extrapolation to temperatures of 20 and 25°C can be made by regression analysis of log p_T vs. 1/T. This method is suitable for substances with vapour pressures as low as 10^{-10} Pa (10^{-12}mbar) and with purity as close as possible to 100% to avoid the misinterpretation of measured weight losses.

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Apparatus

29.   The general principle of the experimental set-up is shown in figure 7.

Figure 7
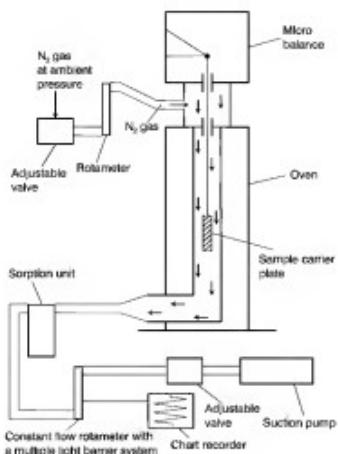
30.   The sample carrier plate, hanging on a microbalance in a temperature controlled chamber, is swept by a stream of dry nitrogen gas which carries the vaporized molecules of the test substance away. After leaving the chamber the gas stream is purified by a sorption unit.

Procedure

31.   The test substance is applied to the surface of a roughened glass plate as a homogeneous layer. In the case of solids the plate is wetted uniformly by a solution of the substance in a suitable solvent and dried in an inert atmosphere. For the measurement, the coated plate is hung into the thermogravimetric analyzer and subsequently its weight loss is measured continuously as a function of time.

32.   The evaporation rate v_T at a definite temperature is calculated from the weight loss Δm of the sample plate by:

$$v_T = \frac{\Delta m}{F \cdot t} \quad (g\,cm^{-2}\,h^{-1})$$

where F is the surface area of the coated test substances, normally the surface area of the sample plate, and t is the time for weight loss Δm.

33.   The vapour pressure p_T is calculated on the basis of its function of evaporation rate v_T :

$$\log p_T = C + D \cdot \log v_T$$

where C and D are constants specific for the experimental arrangement used, depending on the diameter of the measurement chamber and the gas flow rate. These constants must be determined once by measuring a set of compounds with known vapour pressure and regressing log p_T vs. log v_T (11)(21)(22).

34.   The relationship between the vapour pressure p_T and the temperature T in Kelvin is given by:

$$\log p_T = A + B \cdot 1/T$$

where A and B are constants obtained by regressing log p_T vs. 1/T. With that equation, the vapour pressure can be calculated for any other temperature by extrapolation.

Gas saturation method (23)

Principle

35.   Inert gas is passed, at ambient temperature and at a known flow rate, through or over a sample of the test substance, slowly enough to ensure saturation. Achieving saturation in the gas phase is of critical importance. The transported substance is trapped, generally using a sorbent, and its amount is determined. As an alternative to vapour trapping and subsequent analysis, in-train analytical techniques, like gas chromatography may be used to determine quantitatively the amount of material transported. The vapour pressure is calculated on the assumption that the ideal gas law is obeyed and that the total pressure of a mixture of gases is equal to the sum of the pressures of the component gases. The partial pressure of the test substance, i.e. the vapour pressure, is calculated from the known total gas volume and the weight of the material transported.

36.   The gas saturation procedure is applicable to solid or liquid chemicals. It can be used for vapour pressures down to 10^{-10} Pa (10)(11)(12)(13)(14). The method is most reliable for vapour pressures below 10^3 Pa. Above 10^3 Pa, the vapour pressures are generally overestimated, probably due to aerosol formation. Since the vapour pressure measurements are made at ambient temperatures, the need to extrapolate data from high temperatures is not necessary and high temperature extrapolation, which can often cause serious errors, is avoided.

Apparatus

37.   The procedure requires the use of a constant-temperature box. The sketch in Figure 8 shows a box containing three solid and three liquid sample holders, which allow for the triplicate analysis of either a solid or a liquid sample. The temperature is controlled to ±0.5°C or better.

Figure 8
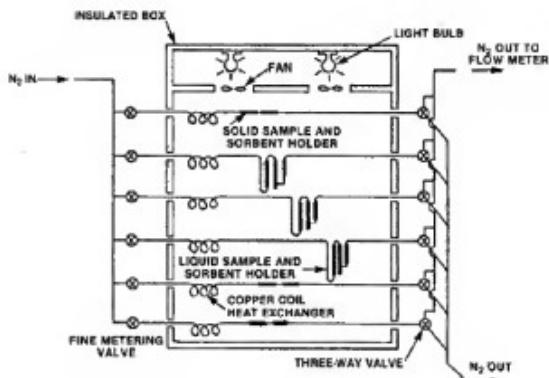
38.   In general, nitrogen is used as an inert carrier gas but, occasionally, another gas may be required (24). The carrier gas must be dry. The gas stream is split into 6 streams, controlled by needle valves (approximately 0.79 mm orifice), and flows into the box via 3.8 mm i.d. copper tubing. After temperature equilibration, the gas flows through the sample and the sorbent trap and exits from the box.

39.   Solid samples are loaded into 5 mm i.d. glass tubing between glass wool plugs (see Figure 9). Figure 10 shows a liquid sample holder and sorbent system. The most reproducible method for measuring the vapour pressure of liquids is to coat the liquid on glass beads or an inert sorbent such as silica and to pack the holder with these beads. As an alternative, the carrier gas may be made to pass a coarse frit and bubble through a column of the liquid test substance.

Figure 9

Figure 10
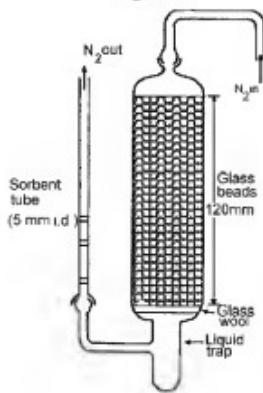
40.   The sorbent system contains a front and a backup sorbent section. At very low vapour pressures, only small amounts are retained by the sorbent and the adsorption on the glass wool and the glass tubing between the sample and the sorbent may be a serious problem.

41.   Traps cooled with solid CO_2 are another efficient way for collecting the vaporised material. They do not cause any back pressure on the saturator column and it is also easy to remove quantitatively the trapped material.

Procedure

42.   The flow rate of the effluent carrier gas is measured at room temperature. The flow rate is checked frequently during the experiment to assure that there is an accurate value for the total volume of carrier gas. Continuous monitoring with a mass flow-meter is preferred. Saturation of the gas phase may require considerable contact time and hence quite low gas flow rates (25).

43.   At the end of the experiment, both the front and backup sorbent sections are analysed separately. The compound on each section is desorbed by adding a solvent. The resulting solutions are analysed quantitatively to determine the weight desorbed from each section. The choice of the analytical method (also the choice of sorbent and desorbing solvent) is dictated by the nature of the test material. The desorption efficiency is determined by injecting a known amount of sample onto the sorbent, desorbing it and analysing the amount recovered. It is important to check the desorption efficiency at or near the concentration of the sample under the test conditions.

44.   To assure that the carrier gas is saturated with the test substance, three different gas flow rates are used. If the calculated vapour pressure shows no dependence on flow rate, the gas is assumed to be saturated.

45.   The vapour pressure is calculated through the equation:

$$p = \frac{W}{V} \times \frac{RT}{M}$$

where:

p =   vapour pressure (Pa) ;
W =   mass of evaporated test substance (g);
V =   volume of saturated gas (m³);
R =   universal gas constant 8.314 (J mol⁻¹ K⁻¹);
T =   temperature (K);
M =   molar mass of test substance (g mol⁻¹).

46.   Measured volumes must be corrected for pressure and temperature differences between the flow meter and the saturator.

Spinning rotor method

Principle

47.   This method uses a spinning rotor viscosity gauge, in which the measuring element is a small steel ball which, suspended in a magnetic field, is made to spin by rotating fields (26)(27)(28). Pick-up coils allow its spinning rate to be measured. When the ball has reached a given rotational speed, usually about 400 revolutions per second, energizing is stopped and deceleration, due to gas friction, takes place.

The drop of rotational speed is measured as a function of time. The vapour pressure is deduced from the pressure-dependent slow-down of the steel ball. The recommended range is 10^{-4} to 0.5 Pa.

Apparatus

48.   A schematic drawing of the experimental set-up is shown in figure 11. The measuring head is placed in a constant-temperature enclosure, regulated within 0.1°C. The sample container is placed in a separate enclosure, also regulated within 0.1°C. All other parts of the set-up are kept at a higher temperature to prevent condensation. The whole apparatus is connected to a high-vacuum system.

Figure 11

A: Spinning rotor sensor head
B: Sampling cell
C: Thermostat
D: Vacuum line (turbo pump)
E: Air thermostat
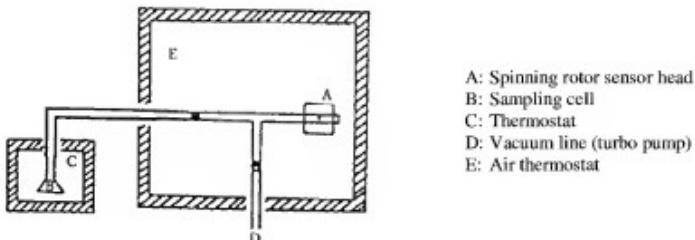
DATA AND REPORTING

Data

49.   The vapour pressure from any of the preceding methods should be determined for at least two temperatures. Three or more are preferred in the range 0 to 50°C, in order to check the linearity of the vapour pressure curve. In case of Effusion method (Knudsen cell and isothermal thermogravimetry) and Gas saturation method, 120 to 150 °C is recommended for the measuring temperature range instead of 0 to 50°C.

Test Report

50.   The test report must include the following information:

- method used;
- precise specification of the substance (identity and impurities) and preliminary purification step, if any;
- at least two vapour pressure and temperature values- and preferably three or more – required in the range 0 to 50°C (or 120 to 150°C);
- at least one of the temperatures should be at or below 25°C if technically possible according to the chosen method;
- all original data;
- a log p versus 1/T curve;
- an estimate of the vapour pressure at 20 or 25°C.

51.   If a transition (change of state, decomposition) is observed, the following information should be noted:

- nature of the change;
- temperature at which the change occurs at atmospheric pressure;
- vapour pressure at 10 and 20°C below the transition temperature and 10 and 20°C above this temperature (unless the transition is from solid to gas).

52.   All information and remarks relevant for the interpretation of results have to be reported, especially with regard to impurities and physical state of the substance.

LITERATURE

(1)   Official Journal of the European Communities L 383 A (1992), 26-47.

(2)   Ambrose, D. (1975). Experimental Thermodynamics, Vol.II, Le Neindre, B., and Vodar, B., Eds., Butterworths, London.

(3)   Weissberger R., ed. (1959). Technique of Organic Chemistry, Physical Methods of Organic Chemistry, 3rd ed., Vol. I, Part I. Chapter IX, Interscience Publ., New York.

(4)   Glasstone, S. (1946). Textbook of Physical Chemistry, 2nd ed., Van Nostrand Company, New York.

(5)   NF T 20-048 AFNOR (September 1985). Chemical products for industrial use – Determination of vapour pressure of solids and liquids within a range from 10^{-1} to 10^5 Pa - Static method.

(6)   ASTM D 2879-86, Standard test method for vapour pressure - temperature relationship and initial decomposition temperature of liquids by isoteniscope.

(7)   NF T 20-047 AFNOR (September 1985). Chemical products for industrial use –Determination of vapour pressure of solids and liquids within range from 10^{-3} to 1 Pa – Vapour pressure balance method.

(8)   Knudsen, M. (1909). Ann. Phys. Lpz., 29, 1979; (1911), 34, 593.

(9)   Ambrose, D., Lawrenson, I.J., Sprake, C.H.S. (1975). J. Chem. Thermodynamics 7, 1173.

(10)   Schmuckler, M.E., Barefoot, A.C., Kleier, D.A., Cobranchi, D.P. (2000), Vapor pressures of sulfonylurea herbicides; Pest Management Science 56, 521-532.

(11)   Tomlin, C.D.S. (ed.) (2000). The Pesticide Manual, Twelfth Edition.

(12)   Friedrich, K., Stammbach, K. (1964), Gas chromatographic determination of small vapour pressures determination of the vapour pressures of some triazine herbicides. J. Chromatog. 16, 22-28

(13)   Grayson, B.T., Fosbracy, L.A. (1982). Pesticide Science 16, 269-278.

(14)   Rordorf, B.F. (1987), Prediction of vapor pressures, boiling points and enthalpies of fusion for twenty-nine halogenated dibenzo-p-dioxins. Thermochimia Acta 112 Issue 1, 117-122.

(15)   Gückel, W., Synnatschke, G., Rittig, R. (1973), A Method for Determining the Volatility of Active Ingredients Used in Plant Protection; Pesticide Science 4, 137-147.

(16)   Gückel, W., Synnatschke, G., Rittig, R. (1974), A Method for Determining the Volatility of Active Ingredients Used in Plant Protection II. Application to Formulated Products; Pesticide Science 5, 393-400.

(17)   Gückel, W., Kaestel, R., Lewerenz, J., Synnatschke, G. (1982), A Method for Determining the Volatility of Active Ingredients Used in Plant Protection. Part III: The Temperature Relationship between Vapour Pressure and Evaporation Rate; Pesticide Science 13, 161-168.

(18)   Gückel, W., Kaestel, R., Kroehl, T., Parg, A. (1995), Methods for Determining the Vapour Pressure of Active Ingredients Used in Crop Protection. Part IV: An Improved Thermogravimetric Determination Based on Evaporation Rate; Pesticide Science 45, 27-31.

(19)   Kroehl, T., Kaestel, R., Koenig, W., Ziegler, H., Koehle, H., Parg, A. (1998), Methods for Determining the Vapour Pressure of Active Ingredients Used in Crop Protection. Part V: Thermogravimetry Combined with Solid Phase MicroExtraction (SPME); Pesticide Science 53, 300-310.

(20)   Tesconi, M., Silkowsky, S.H. (1998), A Novel Thermogravimetric Method for Estimating the Saturated Vapor Pressure of Low-Volatility Compounds; Journal of Pharmaceutical Science 87(12), 1512-20.

(21)   Lide, D.R. (ed.), CRC Handbook of Chemistry and Physics, 81st ed.(2000), Vapour Pressure in the Range -25°C to 150°C.

(22)   Meister, R.T. (ed.) (2002). Farm Chemicals Handbook, Vol. 88.

(23)   40 CFR, 796. (1993), pp 148-153, Office of the Federal Register, Washington D.C.

(24)   Rordorf B.F. (1985). Thermochimica Acta 85, 435.

(25)   Westcott et al. (1981). Environ. Sci. Technol. 15, 1375.

(26)   Messer G., Röhl, P., Grosse G., and Jitschin W. (1987). J. Vac. Sci. Technol. (A), 5(4), 2440.

(27)   Comsa G., Fremerey J.K., and Lindenau, B. (1980). J. Vac. Sci. Technol. 17(2), 642.

(28)   Fremerey, J.K. (1985). J. Vac. Sci. Technol. (A), 3(3), 1715.

ANNEX

ESTIMATION METHOD

INTRODUCTION

1.   Estimated values of the vapour pressure can be used:

- for deciding which of the experimental methods is appropriate;
- for providing an estimate or limit value in cases where the experimental method cannot be
  applied due to technical reasons.

ESTIMATION METHOD

2.   The vapour pressure of liquids and solids can be estimated by use of the modified Watson
correlation (a). The only experimental data required is the normal boiling point. The method is applicable
over the pressure range from 10^5 Pa to 10^{-5} Pa.

3.   Detailed information on the method is given in "Handbook of Chemical Property Estimation
Methods" (b). See also OECD Environmental Monograph No.67 (c).

CALCULATION PROCEDURE

4.   The vapour pressure is calculated as follows:

$$\ln P_{vp} \approx \frac{\Delta H_{vb}}{\Delta Z_b R T_b} \left[1 - \frac{\left(3 - 2\dfrac{T}{T_b}\right)^m}{\dfrac{T}{T_b}} - 2m\left(3 - 2\dfrac{T}{T_b}\right)^{m-1} \ln \frac{T}{T_b} \right]$$

where:

T	=	temperature of interest;
T_b	=	normal boiling point;
P_{vp}	=	vapour pressure at temperature T;
ΔH_{vb}	=	heat of vaporization;
ΔZ_b	=	compressibility factor (estimated at 0.97);
m	=	empirical factor depending on the physical state at the temperature of interest.

Further,

$$\frac{\Delta H_{vb}}{T_b} = K_F (8.75 + R \ln T_b)$$

where, K_F is an empirical factor considering the polarity of the substance. For several compound types, K_F
factors are listed in reference (b).

5.   Quite often, data are available in which a boiling point at reduced pressure is given. In such a case, the vapour pressure is calculated as follows:

$$\ln P_{vp} \approx \ln P_1 + \frac{\Delta H_{v1}}{\Delta Z_b R T_1} \left[1 - \left(3 - 2\frac{T}{T_1} \right)^m \frac{T_1}{T} - 2m \left(3 - 2\frac{T}{T_1} \right)^{m-1} \ln \frac{T}{T_1} \right]$$

where, T_1 is the boiling point at the reduced pressure P_1 .

REPORT

6.   When using the estimation method, the report shall include a comprehensive documentation of the calculation.

LITERATURE

(a)   Watson, K.M. (1943). Ind. Eng. Chem, 35, 398.

(b)   Lyman, W.J., Reehl, W.F., Rosenblatt, D.H. (1982). Handbook of Chemical Property Estimation Methods, McGraw-Hill.

(c)   OECD Environmental Monograph No.67 (1993). Application of Structure-Activity Relationships to the Estimation of Properties Important in Exposure Assessment.